

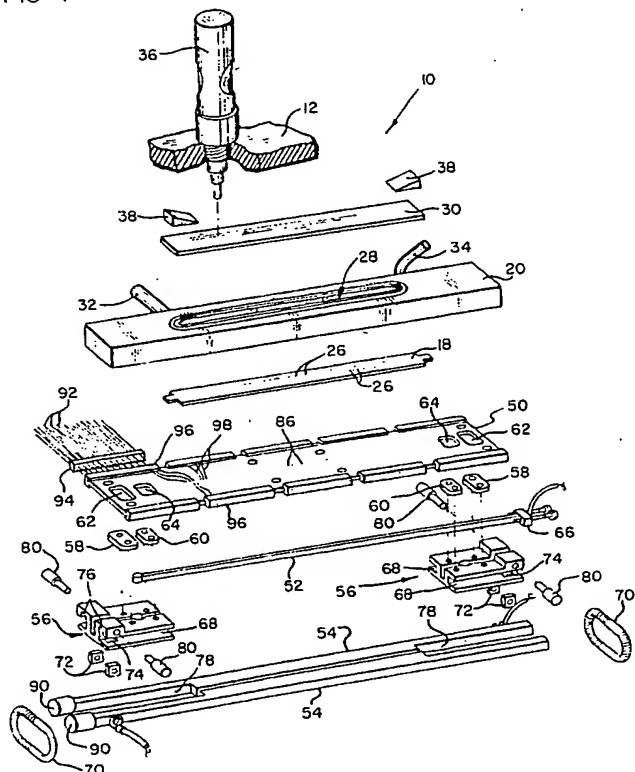
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- (58) Field of search B6F
- (71) Applicant
The Mead Corporation
Mead World Headquarters,
Courthouse Plaza North-
east, Dayton, Ohio 45463,
United States of America.
- (72) Inventors
Charles L. Cha
John A. Robertson
- (74) Agents
Baron & Warren

(54) Jet printer having liquid coupled traveling wave stimulation

(57) A jet drop recording head has an orifice plate (18) defining a plurality of orifices (26) and a common manifold connected with the orifices. A flexible plate (30) communicates with the manifold and defines a fluid reservoir in communication with the manifold and orifice plate. Ink is supplied to the fluid reservoir under pressure to create a line of required jets. A stimulator (36) generates a series of bending waves which travel along the flexible plate means such that the jets are stimulated to break up into streams of regularly formed drops. Means (50, 52, 54) are provided for charging and deflecting the drops to create intelligible patterns. The stimulation of the flexible plate may be applied at one end of the plate or, alternatively, in the center of the plate.

FIG-1



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FIG-1

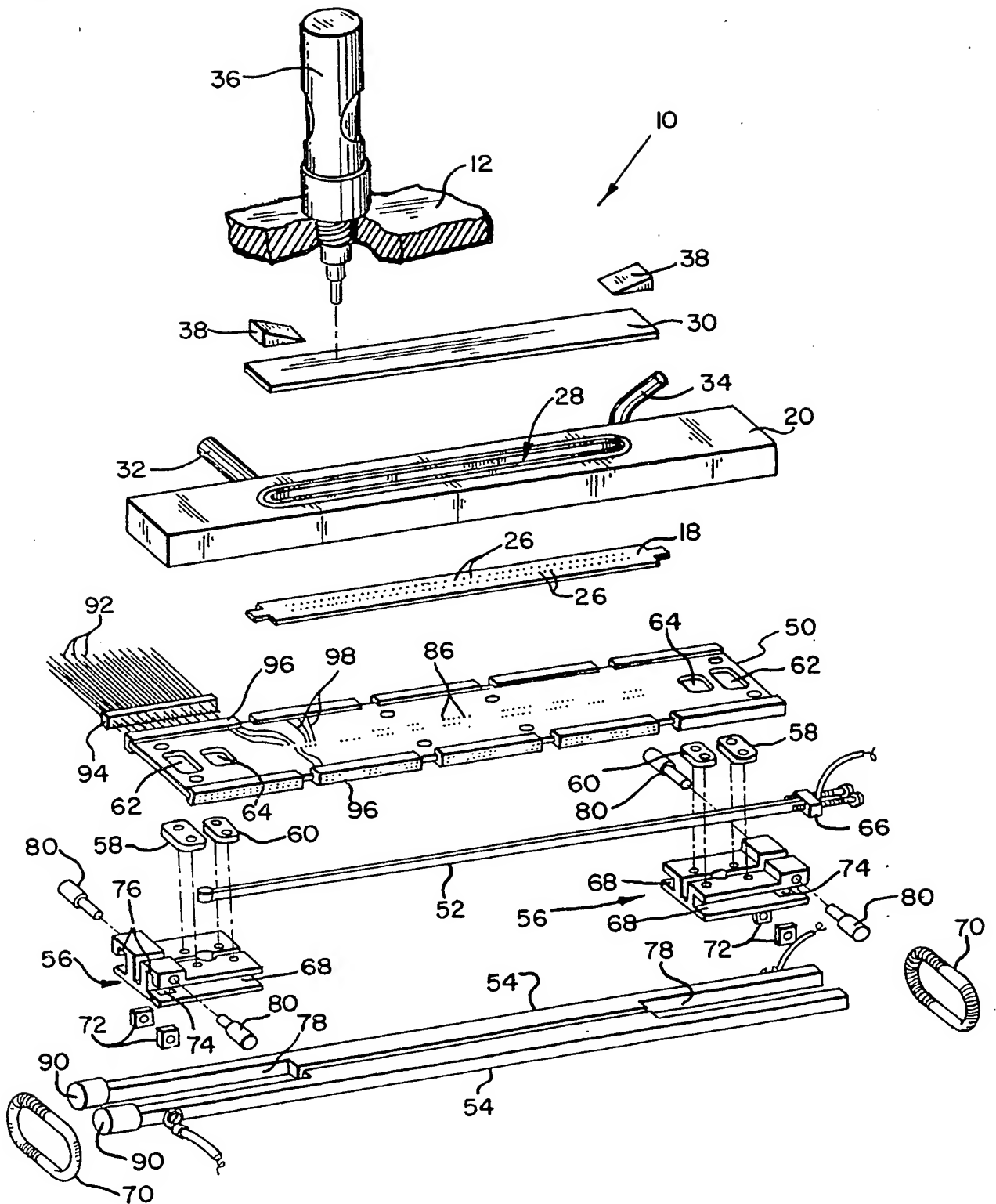


FIG-2

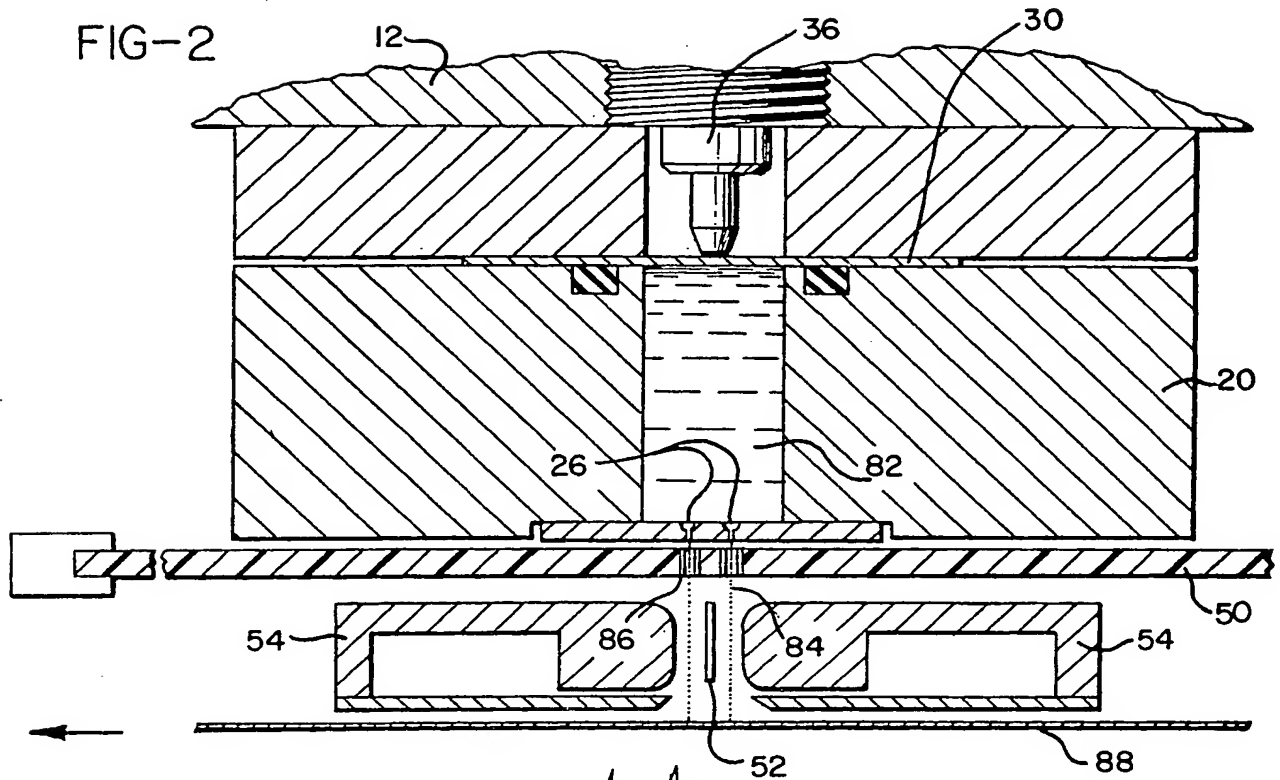


FIG-3

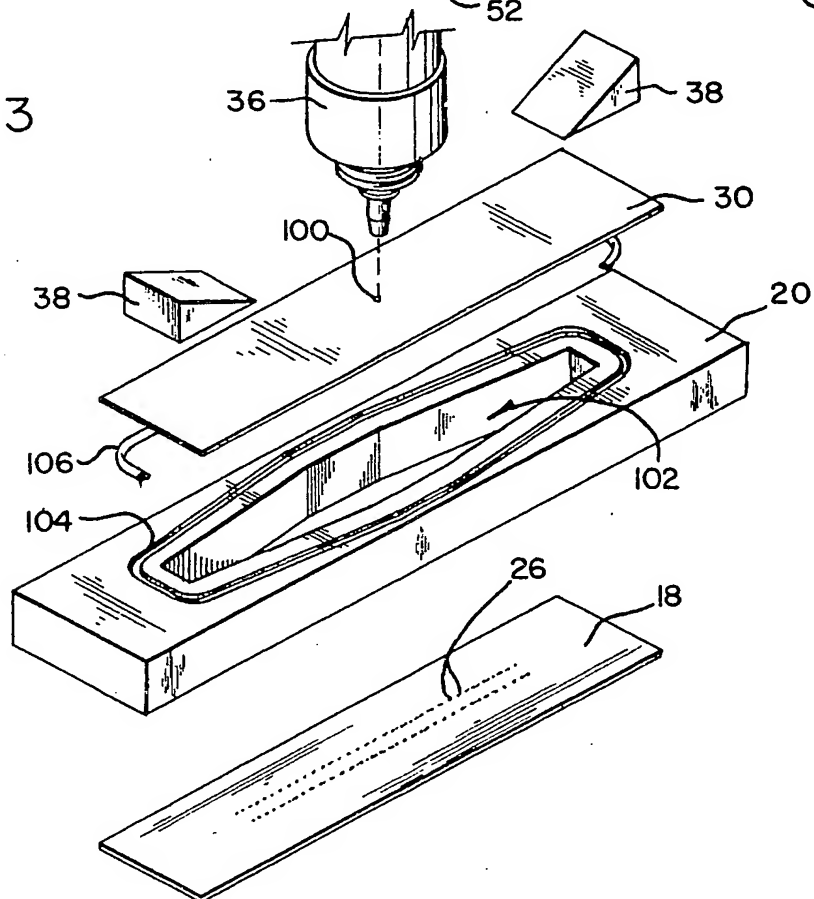


FIG-6

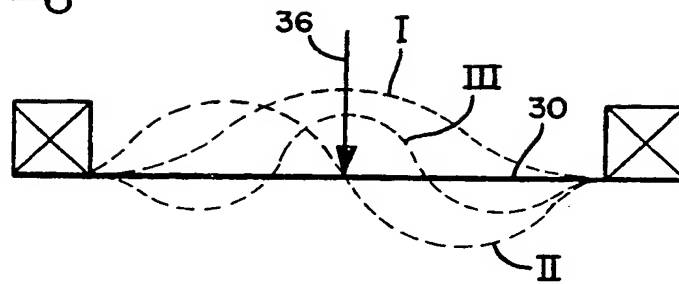


FIG-4

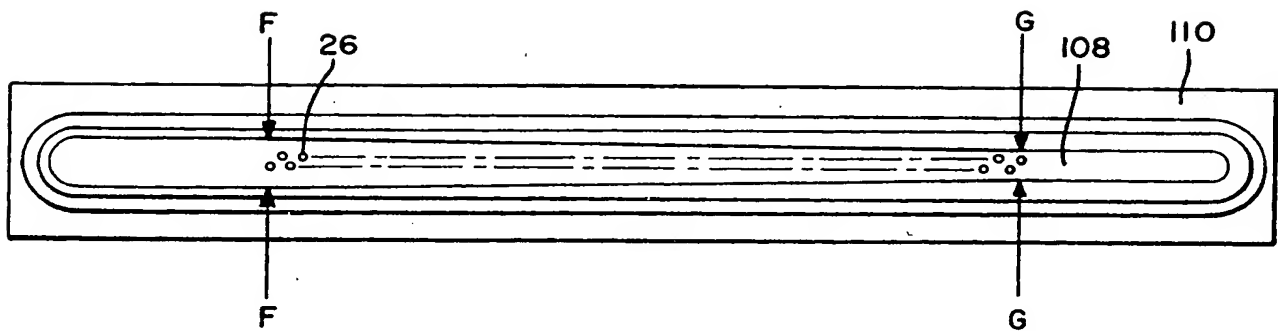
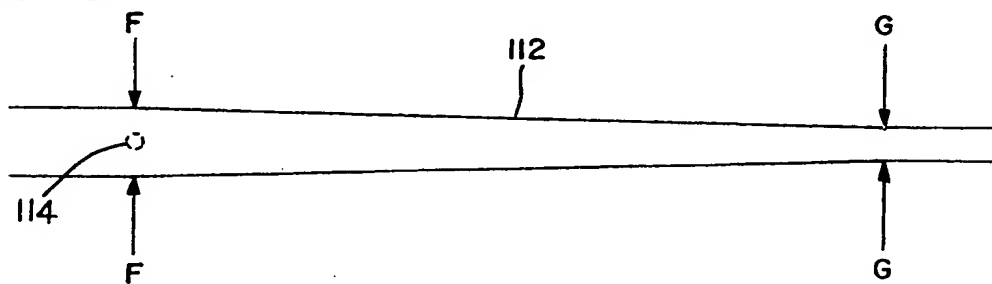


FIG-5



SPECIFICATION

Jet printer having liquid coupled traveling wave stimulation

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The present invention relates to jet drop recorders and, more particularly, to recording devices in which a plurality of ink drops are created by mechanical stimulation. In recorders of the type shown in U.S. Patent No. 3,373,437, issued March 12, 1968, to Sweet et al and U.S. Patent No. 3,560,641, issued February 2, 1971, to Taylor et al, one or more rows of orifices receive an electrically conductive recording fluid, such as for instance a water base ink, from a pressurized fluid manifold and eject the fluid in rows of parallel drop streams. Graphic reproduction is accomplished by selectively charging and deflecting drops in each of the streams and depositing at least some of the drops on a moving web of print material.

Each drop stream is formed as the conductive field flows through an orifice and forms a fluid filament. The drops will be formed at the end of the filaments. If a charging electrode is positioned near the end of the filament, a potential applied to the electrode will induce the accumulation of charge in the tip of the filament. As a drop breaks from the tip of the filament, it will carry a portion of this induced charge. Thereafter, the drop will pass through an electrostatic field and will be deflected by the field a distance which is proportional to the magnitude of a drop charge. In a preferred embodiment, the drops will be charged in binary fashion for a print or no print operation; some drops are charged and deflected to a catching device while others are uncharged and thus pass unaffected through the field and onto a print web.

It will be appreciated that it is necessary to control drop formation in such a recording device with a high degree of precision. If left to natural stimulating disturbances, the fluid filaments would tend to break up erratically into drops of varying size at irregular intervals. Selective charging and deflection could not be performed on a uniform basis and therefore it would not be possible to print images of acceptable quality. Accordingly, it has been known to apply a fixed frequency, constant magnitude stimulating disturbance to all of the fluid streams. This results in trains of uniformly sized regularly spaced drops and enables reasonably good recording. Such a system is shown in U.S. Patent No. 3,586,907, issued June 22, 1971 to Beam et al. In the Beam et al device, the entire print bar is mechanically stimulated by a sonic vibrator.

Drop stimulation techniques in which the entire print bar or the fluid supply are vibrated provide uniform ink drops, but the drop stimulation varied in phase uncontrollably and unpredictably from stream to stream. This caused a timing uncertainty on the order of one-half of a drop repetition period. A noticeable drop position or placement error resulted which was equal to the movement of the print web during one-half drop repetition period. Additionally, stimulation of this type resulted in an unpredictable variation in stimulation energy amplitude between

the drop streams and corresponding variation in the length of fluid filaments. This variation in filament length may correspond to a distance as great as ± 3 drop spacing distances. It will be extremely difficult, therefore, to position the charge electrode at a point near the filament end. Timing variations will also be introduced between the various drop streams since the distance which the drops have to fall before striking the print web will vary between streams. Drop flight time will differ and drop positioning on the print web will be adversely affected.

A drop stimulation technique is disclosed in U.S. Patent No. 3,739,393, issued June 12, 1973, to Lyon et al, which eliminates a number of the problems which have occurred with respect to drop stimulation. In the Lyon et al patent, a stimulation arrangement is disclosed in which the jets are stimulated by a traveling wave which is propagated along the orifice plate. Bending waves are transmitted past each orifice and impart a drop disturbance to the associated jet. This technique eliminates erratic variations in fluid filament length and results in the achievement of high quality stimulation.

One difficulty with the technique disclosed in the Lyon et al patent is that the bending waves are attenuated as they travel along the length of the orifice plate. This, in turn, causes a progressive lengthening of the jet filaments so that the filament at the far end of the orifice plate may be considerably longer than those which are near the source of the bending wave stimulation. In order to overcome this undesirable attenuation of the bending waves, U.S. Patent No. 3,882,508, issued May 6, 1975, to Stoneburner, discloses a jet recorder having an orifice plate and head construction in which the head is tapered and the active width of the orifice plate gradually decreases along the path of the bending wave movement. Since the mass vibrated will be gradually reduced, the energy available for application of the filaments will be more uniform and the filament length will tend to remain more uniform.

While stimulating drop formation by applying a traveling wave to the orifice plate presents significant advantages over stimulation by vibration of the entire print head, the construction of the orifice plate is necessarily constrained in such a printer in terms of the vibrational characteristics required. The orifice plate must necessarily be sufficiently flexible to be stimulated by a transducer. Thus it may not be possible to use certain materials for orifice plate construction, even though such materials may be easily worked or machined to produce a plate having the precise dimension, form and spacing of orifice holes desired.

Although tapering the orifice plate width in a system in which traveling waves are applied to the orifice plate may provide more uniform stimulation amplitude, there are maximum and minimum orifice plate widths which are acceptable. If these maximum and minimum dimensions are exceeded, the orifice plate may vibrate in undesirable width-wise vibrational modes, and waves may be reflected along the length of the plate as explained in the Stoneburner patent.

The maximum length of the print bar may be

further extended by providing for stimulation of the plate at a central point with waves traveling in both directions along the plate with a tapering of the orifice plate in both directions. The difficulty with this technique, however, is that the actual point of mechanical stimulation must be slightly offset from the orifice rows. Stimulation of the orifice plate at a point which is not on the longitudinal center axis will result in undesired bending. The Stoneburner patent disclosure suggests using the orifice plate which is thickened near the point of excitation to suppress these undesired bending modes. Such a design may be somewhat difficult to implement.

A jet drop recording head has an orifice plate which defines a plurality of orifices arranged along a line. A common manifold connects with the orifice, and means are provided for marginally securing the orifice plate to the manifold. A flexible plate means communicate with the manifold and defines a fluid reservoir in conjunction with the manifold and the orifice plate. The flexible plate means extend the length of the reservoir parallel to the orifice plate. Means are provided for supplying ink to the fluid reservoir at a pressure sufficient to force the ink through the orifices and to create a line of liquid jets. Stimulator means is provided for causing a series of bending waves to travel along the flexible plate means such that the jets are stimulated into breaking up into streams of regularly formed drops. Means are provided for charging and deflecting the drops to create intelligible patterns therefrom.

The stimulator means may be positioned to apply mechanical stimulation to the first end of the flexible plate means whereby bending waves induced in the first end will travel along the flexible plate means to a second end. Damping means may be provided at the first and second ends of the flexible plate means to prevent reflection of the bending waves at the ends and thereby to minimize standing waves which may result from such reflection. The width of the flexible plate means may be narrowed toward the second end so that attenuation of the bending waves along the plate means may be compensated. Alternatively, the stimulator means may be positioned to apply mechanical stimulation at a point which is intermediate the first and second ends of the flexible plate means. In such an arrangement, the manifold may define a boat shaped fluid reservoir in which the reservoir is widest at its center and narrows toward its first and second ends.

Accordingly, it is an object of the present invention to provide a jet drop recording head having a stimulator configuration in which traveling waves along a portion of the reservoir structure remote from the orifice plate are liquid coupled to the orifices in the orifice plate and provide a source of drop inducing disturbance in the fluid; to provide such a recording head in which the traveling waves are bending waves which move along a flexible plate defining a portion of the fluid reservoir; to provide such a recording head in which the flexible plate is tapered and mechanical stimulation is applied to a wide portion of the plate, whereby wave attenuation is minimized; and, to provide such a device in which stimulation is applied to the central area of the plate

with traveling waves moving from the point of stimulation in both directions longitudinally along the plate.

In order that the present invention may be more readily understood, reference will now be made to the accompanying drawings, in which:—

Figure 1 is an exploded perspective view of a recording head assembly of the present invention;

Figure 2 is a cross sectional view taken through the assembly of Fig. 1;

Figure 3 is an exploded perspective view of a portion of an alternative embodiment of the recording head assembly of the present invention;

Figure 4 is a plan view showing an orifice plate and manifold of a further embodiment of the present invention;

Figure 5 illustrates the active portion of the flexible plate used with the orifice plate and manifold of Fig. 4; and,

Figure 6 is a schematic representation of three different resonance modes for an orifice plate across the width of the plate.

A preferred embodiment of this invention is illustrated in exploded perspective form in Fig. 1. The various elements of the head are assembled by attachment to supporting structure 12. Assembly thereto is accomplished by attaching the elements by means of screws and clamps (not shown).

The recording head comprises an orifice plate 18, which is soldered, welded or otherwise bonded to a fluid supply manifold 20. Orifice plate 18 may be formed of any material which can be drilled or machined to provide the desired orifice configuration. Orifice plate 18 preferably defines two rows of orifices 26. Manifold 20 defines a central ink reservoir cavity 28 having upper and lower openings, the openings being substantially elongated. Orifice plate 18 is mounted to cover the lower opening in the manifold with the orifice rows extending substantially parallel to the direction of elongation of the manifold openings. A flexible plate 30 is mounted to cover the upper opening in manifold 20. Tube 32 provides a means of supplying ink to the fluid reservoir at a pressure sufficient to force the ink through orifices 26 and to create a plurality of rows of ink jets. Tube 34 provides an exhaust from the reservoir.

Stimulator 36 is mounted in support bar 12 and contacts flexible plate 30 such that it provides a mechanical stimulation to plate 30. Bending waves travel along plate 30 in a direction which is parallel to the elongation of the openings in the manifold 20. The bending waves in plate 30 are coupled to the jets through the fluid in the reservoir 28 such that the jets are stimulated to break up into streams of regularly formed drops. A pair of wedge-shaped acoustical dampers 23 are mounted at each end of plate 30. Dampers 23 are typically formed of polyurethane rubber or similar material and act to absorb the bending waves. The bending waves are therefore generally not reflected and standing wave patterns are thereby prevented. The rows of regularly formed ink drops are charged and deflected to create desired patterns, as described below.

A charge ring plate 50, an electrically conductive deflection ribbon 52, and a pair of catchers 54 pro-

vide the major elements needed for charging and deflecting the drops such that intelligible patterns may be created. Catchers 54 are supported by holders 56 which are attached directly to fluid manifold 20. Spacers 58 and 60 reach through apertures 62 and 64, respectively, in charge ring plate 50 to support holders 56 without stressing or constraining charge ring plate 50. Deflection ribbon 52 is also supported by holders 56 and is stretched tightly therebetween by means of tightening block 66. Ribbon 52 extends between catchers 54, as best shown in Fig. 2.

Catchers 54 are laterally adjustable with respect to ribbon 52. This adjustability is accomplished by assembling the head and catchers 54 resting in slots 68 of holders 56, and urging them mutually inward with a pair of elastic bands 70. Adjusting blocks 72 are inserted upwardly through recesses 74 and 76 to bear against faces 78 of catchers 54 and adjusting screws 89 are provided to drive adjusting blocks 72 and catchers 54 outwardly against elastic band 70. Holders 56 are made of insulated material which may be any available reinforced plastic board.

The fully assembled recording head is shown in cross section in Fig. 2. As therein illustrated, coating fluid 82 flows downwardly through orifices 26 forming two rows of streams which break up into drops 84. Drops 84 then pass through two rows of charge rings 86 in charge ring plate 50 and thence into one of the catchers 54 or onto the moving web of paper 88. Switching of drops between "catch" and "deposit" trajectories is accomplished by electrostatic charging and deflection as hereinafter described. Coordinated printing capability is achieved by staggering the two rows of streams in accordance with the teachings of Taylor et al, U.S. Patent No. 3,560,640. As therein described, the drops in the forward row of streams (i.e., the row most advanced in the direction of web movement) are switched in a time reference frame delayed from that of the rear row by a time d/V , where d is the row spacing and V is the web speed. This produces a coherence such that the two rows of streams function as a single row with an effective stream spacing equal to half the actual spacing in either of the real rows.

Formation of drops 84 is closely controlled by application of a constant frequency, controlled amplitude stimulating disturbance to each of the fluid streams emanating from orifice plate 18. Disturbances for this purpose are set by operating transducer 36 to vibrate flexible plate 30 at constant amplitude and frequency. This generates a continuing series of bending waves which travel the length of plate 30. These bending waves are transmitted through the fluid 82 in the reservoir to the fluid forming the filaments emerging from orifices 26. Dampers 28 are mounted on the upper surface of plate 30 and prevent reflection of the bending waves. It should be understood, however, that dampers 38 could be mounted beneath the plate 30 in reservoir 28.

As each group 84 is formed, it is exposed to the charging influence of one of the charge rings 86. This causes an electrical charge to be induced in the tip of the fluid filament and carried away by the drops. A

static electrical field is set up between deflection ribbon 52 and the faces of each of the catchers 54. When the drop 84 traverses this field it is deflected to strike the face of the appropriate catcher. Thereafter, the drop runs down the face of the catcher, is ingested, and carried off. Drop ingestion may be promoted by application of a suitable vacuum to the ends 90 of catchers 54. For drops which are to be deposited on the web 88, no electrical charge is applied to the associated charge ring and, therefore, the drop will not be charged.

Appropriate charges for the desired drop charging are induced by setting up an electrical potential difference between orifice plate 18 (or any other conductive structure in electrical contact with the coating fluid supply) and each appropriate charge ring 86. These potential differences are created by grounding plate 18 and applying appropriately timed voltage pulses to wires 92 and connectors 94 (only one connector illustrated). Connectors 94 are plugged in the receptacles 96 at the edge of charge ring plate 50 and deliver the mentioned voltage pulses over printed circuit lines 98 to charge rings 86. Charge ring plate 50 is fabricated from insulative material and charge rings 86 are merely coatings of conductive material lining the surfaces of orifices in the charge ring plate. Voltage pulses for the above purpose are generated by circuits of the type disclosed in Taylor et al, above, and wires 92 receiving these pulses may be matched with charge rings on a one-to-one basis. Also, the voltage pulses may be multiplexed to decrease the number of wires and connectors. As an alternative embodiment, solid state demultiplexing circuits may be employed to demultiplex the signals and route the pulses the proper charge rings. Such solid state circuits are manufactured by known methods as a permanent part of charge ring 50.

As this will be appreciated, from the above, the use of printing fluid coupling between the flexible plate 30, to which traveling wave stimulation is applied, and the orifices 26 results in a stimulation technique in which the flexibility of the orifice plate 18 is unimportant. As each bending wave moves past a point on the plate 30, a compression wave will be transmitted downwardly from that point through the fluid to the orifices below. The resulting fluid pressure variation will cause drop formation in accordance with the well known Rayleigh jet break-up phenomenon.

Referring now to Fig. 3, an exploded view of the upper portion of an alternative ink jet printer embodying the present invention is shown. As with the embodiment of Figs. 1 and 2, a transducer 36 applies mechanical stimulation to flexible plate 30 causing a series of bending waves to travel along the plate. The plate 30 is stimulated at point 100 which is in the middle of the plate. Bending waves are therefore transmitted in both directions along plate 30 and are absorbed at both ends by bumpers 38.

The manifold 20 may define a boat-shaped fluid reservoir 102 which is widest at its center and which narrows towards the ends. A groove 104 surrounds the reservoir and receives gasket 106 which provides a fluid tight seal between the manifold 20 and flexi-

ble plate 30. Bending waves are transmitted in both directions longitudinally along plate 30. Since the width of the plate is gradually reduced toward each end, the stimulation will remain substantially constant along the length of the reservoir. Although the bending wave will be attenuated slightly, the effective width of plate 30 and the volume of ink in reservoir 102 which will receive the stimulating wave will be sufficiently reduced. It will be appreciated that the orifices 26 extend along the entire length of reservoir 102 and that such orifices may be positioned directly beneath mechanical stimulator 13. The maximum length of the ink jet print bar using center stimulation is therefore double that which may be obtained with a bar which is stimulated at an end.

Reference is now made to Figs. 4 and 5 in which a further embodiment of the present invention is shown. Fig. 4 is a plan view of the orifice plate 108 and manifold 110 and, as may be seen, the manifold 110 defines a reservoir which is tapered from left to right. Fig. 5 represents schematically the active portion of the flexible plate 112 which is used with the manifold 110 of Fig. 4. The dotted circle 114 represents the point at which the stimulator contacts the plate. It will be appreciated that this arrangement, in a manner similar to that described with respect to the center stimulation configuration of Fig. 3, will compensate somewhat for the reduction in bending wave amplitude which will necessarily occur as the waves are transmitted along the flexible plate 112.

Fig. 6 is a schematic representation of the flexible plate 30 and stimulator 36, as seen looking from one end of the plate. As taught by the Lyon et al and Stoneburner patents, it is desirable that the bending waves which travel along the length of an orifice plate in a system in which the orifice plate is stimulated be the first order widthwise resonance mode. Similarly, it is desirable in the stimulation arrangement of the present invention that the bending waves which travel along the length of the flexible plate 30 also be of first order widthwise resonance mode as shown by the dotted line I of Fig. 6. If the flexible plate 30 is sufficiently wide, it will also be possible to generate a series of waves of the second order widthwise resonance mode, as shown by the dotted line II of Fig. 6. A still wider flexible plate 30 would permit generation of bending waves of the third order widthwise resonance mode, as shown by the dotted line III. There also will be a minimum width of active flexible plate area which is needed to support even the first order widthwise resonance mode bending wave. It will be apparent, therefore, that the width of the reservoir and active flexible plate area at F, in Figs. 4 and 5, will be chosen such that it is less than the minimum width to support second order bending waves. The width of the reservoir and active flexible plate area at G will necessarily be at least as large as the width needed to support first order bending waves. It is seen, therefore, that the taper between plates F and G is limited by these considerations. Consequently, the length of print bar which may be effectively compensated by tapering in this manner is also limited.

It should now be apparent that the stimulation arrangement of the present invention provides a

number of distinct advantages over prior art systems which use traveling wave stimulation of the orifice plate. The orifice plate and the flexible plate may each be made of a material which is chosen to best perform the desired functions. Specifically, the flexible plate may be made from a single layer of sheet metal chosen to minimize attenuation of the bending waves. The orifice plate need not be formed of thin, elastic material but may be made of ceramic or glass, for instance, without regard to flexibility. Since the stimulator is not placed in the ink reservoir, the problems associated with this arrangement, including turbulent ink flow and stimulator corrosion, are eliminated.

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CLAIMS

1. A jet drop recording head comprising an orifice plate defining a plurality of orifices arranged along a line, a common manifold connecting with said orifices, means marginally securing said orifice plate to said manifold, flexible plate means communicating with manifold and defining a fluid reservoir in conjunction with said manifold and said orifice plate and extending the length of said reservoir, means for supplying ink to said fluid reservoir at a sufficient pressure to force the ink through the orifices and to create a link of liquid jets, stimulator means for causing a series of bending waves to travel along said flexible plate means for stimulating said jets to break up into streams of regularly formed drops, and means for charging and deflecting said drops to create intelligible patterns therefrom.

2. A jet drop recording head as claimed in claim 1, in which said stimulator means is positioned to apply mechanical stimulation to a first end of said flexible plate means, thereby inducing bending waves in said first end which travel along said flexible plate means to a second end thereof.

3. A jet drop recording head as claimed in claim 2, in which damping means are provided at said first and second ends of said flexible plate means to prevent reflection of said bending waves at said ends.

4. A jet drop recording head as claimed in claim 2, in which said manifold defines a reservoir of decreasing width from a first end adjacent the point at which said stimulator is positioned to a second end remote therefrom.

5. A jet drop recording head as claimed in claim 1, in which said manifold defines a boat-shaped fluid reservoir, which reservoir is widest near its center and narrows toward its ends.

6. A jet drop recording head as claimed in claim 5, in which said stimulator means is positioned to apply mechanical stimulation at a point which is substantially in the center of said flexible plate means.

7. A jet drop recording head as claimed in claim 6, in which damping means are provided at said ends of said flexible plate means to prevent reflection of said bending waves at said ends.

8. A jet drop recording head comprising: a manifold defining a central ink reservoir cavity with upper and lower openings, said openings being substantially elongated,

- an orifice plate defining a plurality of orifices arranged in a plurality of parallel rows, said orifice plate mounted to cover said lower opening in said manifold with said orifice rows extending substantially parallel to the direction of elongation of said openings,
- a flexible plate mounted to cover said upper opening in said manifold,
- means for supplying ink to said fluid reservoir at a sufficient pressure to force the ink through the orifices and to create a plurality of rows of ink jets,
- stimulator means for applying mechanical stimulation to said flexible plate such that a plurality of bending waves travel along said flexible plate in a direction parallel to the elongation of said openings, said waves being coupled to said jets by the ink in said ink reservoir to cause said jets to break up into streams of regularly formed drops, and
- means for charging and deflecting preselected ones of said regularly formed drops to create desired patterns therefrom.
9. A jet drop recording head substantially as hereinbefore described with reference to the accompanying drawings.